SOUTH DAKOTA FISHERIES

Bluegill Population Dynamics and Reproduction in South Dakota Waters

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**Completion Report
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Bluegill Population Dynamics and Reproduction in South Dakota Waters

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ABSTRACT

Bluegill *Lepomis macrochirus* are an important prey species and important sport fish. Therefore, knowledge of reproduction and subsequent recruitment is essential for fishery biologists. Bluegills are typically considered multiple spawners. Protracted reproduction is likely a response to various environmental factors and obviously may influence subsequent recruitment. However, little is known about bluegill spawning periodicity in eastern South Dakota impoundments. Thus, the objectives of this study were to 1) determine the best aging structure for eastern South Dakota bluegill populations, 2) relate bluegill recruitment patterns to abiotic (i.e., climatic) factors, and 3) assess the extent and duration of the bluegill spawning season in four eastern South Dakota impoundments.

For the first objective, bluegills were collected from two small South Dakota impoundments. Little Moreau Lake is a 15-ha impoundment in Dewey County and Lake Louise is a 66-ha impoundment located in Hand County. All fish were collected during standard trap-net surveys conducted by the South Dakota Department of Game, Fish and Parks personnel. Scales provided age assignments similar to those from sagittal otoliths over the first 5 years of bluegill lifespan. However, scale ages were consistently underestimated for older bluegills in comparison with the otoliths. When accurate age-structure assessment or mortality rate determination is required, we recommend that South Dakota bluegill populations be aged with sagittal otoliths.

The second objective of the study was to quantify recruitment patterns and model the relation between climatic variables and year-class strength. Bluegills were collected from four impoundments during the summer of 2004 using modified-fyke nets. The residual method, based on otolith age structure, was used to index relative year-class strength of bluegill cohorts by population. Relations between year-class strength and climatic variables was assessed based on *a priori* models and Akaike's information criterion analysis. Because year-class strength of many species in the northern Great Plains can be erratic due to abiotic factors, we hypothesized that weather patterns during critical times of the year may affect bluegill survival and thus subsequent recruitment. We determined that bluegill recruitment patterns in these four impoundments functioned on an individualized scale. We then assessed the extent to which climatological patterns were related to bluegill recruitment. Akaike weights were comparable among all six *a priori* models we developed. All single variables models (mean temperature, total precipitation, and cooling degree days) exhibited similar support and of the three single variable models, precipitation was the most supported. However, the bivariate plot between precipitation and recruitment exhibited a week positive trend. Thus, if climatological factors influence bluegill recruitment patterns in South Dakota impoundments, the factors are likely complex and interrelated.

For the final objective, larval bluegills were collected from four impoundments during the spawning seasons of 2005 and 2006 using a 0.75-m diameter ichthyoplankton net with a flow meter mounted in the mouth of the trawl to estimate larval density. Ages of larval fish were quantified using sagittal otoliths to determine hatch date. Peak larval bluegill abundances were highly variable among impoundments during both years. In 2005, peak larval abundances were unimodal in all impoundments and peaked in late June in all impoundments. However, in 2006 larval abundances had multiple modes in three out of the four impoundments. Based on otolith daily ring counts we estimated that bluegill populations had spawning durations as short as 38 d and as long as 77 d. The differential timing of bluegill spawning in different years might have implications not only for bluegill recruitment but also for predators such largemouth bass *Micropterus salmoides*. The prolonged bluegill season in 2006 may have provided an extended length range of prey for age-0 piscivores, thereby increasing their chances of overwinter survival.

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CHAPTER 1. INTRODUCTION

The bluegill (*Lepomis macrochirus*) is a widely distributed sport and prey fish in North America. In small South Dakota impoundments, bluegills are an important prey source for many fishes and are an ecologically important species. In addition, they are emerging as a popular sport fish in the Midwestern U.S.A., including South Dakota. According to the latest national survey of fishing, hunting and wildlife associated recreation (USDI 2001), panfish (primarily yellow perch *Perca flavescens*, bluegill, and crappie *Pomoxis* spp.) is the second most targeted fish by South Dakota anglers. As the popularity of bluegill increases among South Dakota anglers so has the demand for improved bluegill fisheries.

Previous South Dakota impoundment research has centered on the predator-prey relationship between largemouth bass *Micropterus salmoides* and bluegills, but the primary focus was on the utility of largemouth bass as a predator to control recruitment and thus create high quality bluegill fisheries (Guy and Willis 1990). High quality bluegill populations were present when largemouth bass catch per unit effort (CPUE; indexed as number of stock-length bass caught per hour of night electrofishing) was high. Correspondingly, high-density largemouth bass populations exhibited lower size structure (i.e., populations dominated by bass <30 cm in total length) and slower growth than low-density bass populations. Bluegill proportional size distribution (PSD; the percentage of 8-cm and longer bluegills that also exceed 15 cm) was always <50 when largemouth bass electrofishing CPUE <40/hr; bluegill PSD was >60 when bass electrofishing CPUE was >80/hr.

Guy and Willis (1991) reported that largemouth bass relative abundance was significantly and positively correlated with submergent aquatic vegetation coverage in small South Dakota impoundments, but correlations coefficients never exceeded 0.65. Hill and Willis (1993) reported that largemouth bass biomass ranged from 10 to 100 kg/ha (mean = 73 kg/ha) in 10 small South Dakota impoundments. When mean DC electrofishing CPUE for stock-length largemouth bass exceeded 100/hr, biomass was always at least 80 kg/ha. At electrofishing CPUE values of 9-12/hr, biomass only ranged from 10 to 26 kg/ha (Hill and Willis 1993, 1994). Thus, at low levels of largemouth bass biomass, some factors must be regulating bass recruitment and subsequent density. A multiple regression model developed for 20 small South Dakota impoundments, with largemouth bass relative abundance as the dependent variable, had $R^2 = 0.51$ for the independent variables submergent vegetation coverage and Secchi transparency (Guy and Willis 1991). Thus, 49% of the variability was not accounted for in this particular assessment. One factor that could influence largemouth bass recruitment is prey availability, and the bluegill is a common fish prey utilized in small impoundment management. The multiple spawning characteristics of bluegills make them a desirable prey species for age-0 largemouth bass because the later-spawned bluegills provide a source of small-sized fish prey for gape-limited bass later in the growing season (Garvey et al. 2002a).

The extended spawning season commonly assumed for bluegill (Cargnelli and Gross 1996; Garvey et al. 2002) was documented in Crane Lake, Indiana, where larval bluegills were collected from early June to early September (Werner 1969). Beard (1982) reported bluegills spawning season lengths as short as 31 d and as long as 112 d in three Wisconsin lakes. Garvey et al. (2002b) reported two peaks in bluegill nesting, once in late May and again in mid-June, in

Lake Opinicon, Ontario; inshore densities of larval bluegills peaked once in late May and again in early July. Chvala (2000) evaluated the reproductive biology of bluegills in two natural lakes in the Nebraska Sandhills. While larvae were first collected in both lakes during June, the spawning season was extended (7-week duration) at one lake, but quite brief at the other lake. Newly hatched (i.e., 4-6 mm) larvae were collected at Cozad Lake between June 5 and July 24, while newly hatched larvae were only collected from Pelican Lake between June 25 and July 9. Egg-diameter distributions from bluegill ovaries in both lakes had multiple modes, indicating multiple-spawning capabilities. A current focus for bluegill research within the fisheries profession is reproductive biology (Dominey 1981; Belk and Hales 1993; Beard et al. 1997; Drake et al. 1997; Ehlinger 1997; Jennings et al. 1997; Aday et al. 2002). However, limited information on bluegill spawning periodicity in small South Dakota impoundments is available, and studies identifying the extent and duration of bluegill spawning may provide insight into the complex mechanisms regulating recruitment of both bluegill and largemouth bass. The objectives of this study were to assess the most appropriate aging strategy for bluegills in South Dakota waters, use that information to assess bluegill year-class strength in four South Dakota impoundments, and then determine the extent and duration of bluegill spawning in those four impoundments.

CHAPTER 2. COMPARISON OF AGES DETERMINED FROM BLUEGILL SCALES AND OTOLITHS

Introduction

Accurate fish ages are important for proper application of standard methods such as growth analysis, age-structure analysis, and mortality rate determination. Accuracy of bluegill ages from sagittal otoliths was validated by Hales and Belk (1992). Hoxmeier et al. (2001) subsequently reported that bluegill age estimates for scales were less precise than those for otoliths. However, these authors also reported that latitude affected the precision of scale age estimates. Across even the latitudinal gradient found in Illinois, they reported that precision of scale age estimates improved for higher lower (i.e., northern) latitudes. Therefore, the objective of this study was to compare age estimates determined from scales and sagittal otoliths for bluegills collected from two South Dakota impoundments.

Methods

Bluegills were collected from two small South Dakota impoundments. Little Moreau Lake is a 15-ha impoundment in Dewey County, and Lake Louise is a 66-ha impoundment located in Hand County. All fish were collected during standard trap-net surveys conducted by the South Dakota Department of Game, Fish and Parks (SDGFP) at Little Moreau Lake (June 23, 2004) and Lake Louise (June 8, 2004). These nets have a bar mesh size of 19 mm, which did retain bluegills as small as 70 mm (total length; TL).

Bluegills were assigned an identification number, weighed, and measured to the nearest millimeter (TL). Scales were removed at the tip of the pectoral fin, and below the lateral line (DeVries and Frie 1996). Sagittal otoliths were then removed from each fish as described by Secor et al. (1991).

Scales were pressed into acetate strips with a roller press, and aged by SDGFP personnel using a microfiche reader. Sagittal otoliths were wiped to ensure cleanliness, returned to South Dakota State University, and stored in plastic vials for a minimum of 2 weeks prior to annulus enumeration. Otoliths were aged based on enumeration of annuli from the whole view through age 5 (Hales and Belk 1992). If the whole view annulus count exceeded 5 (i.e., age-6 and older bluegills), then otoliths were cracked (broken in half through the nucleus and perpendicular to the longest axis), wet sanded, placed in clay, and viewed with a fiber optic light under a binocular microscope at 40X magnification after immersion oil was applied.

Results

The Little Moreau population sample (N=45) was dominated by young fish; 91% of the fish were ages 2-5 and only one exceeded age 6 (Figure 2-1). Agreement between scale and otolith ages was very high. Disagreements occurred for only five fish, and in all cases the age difference was one.

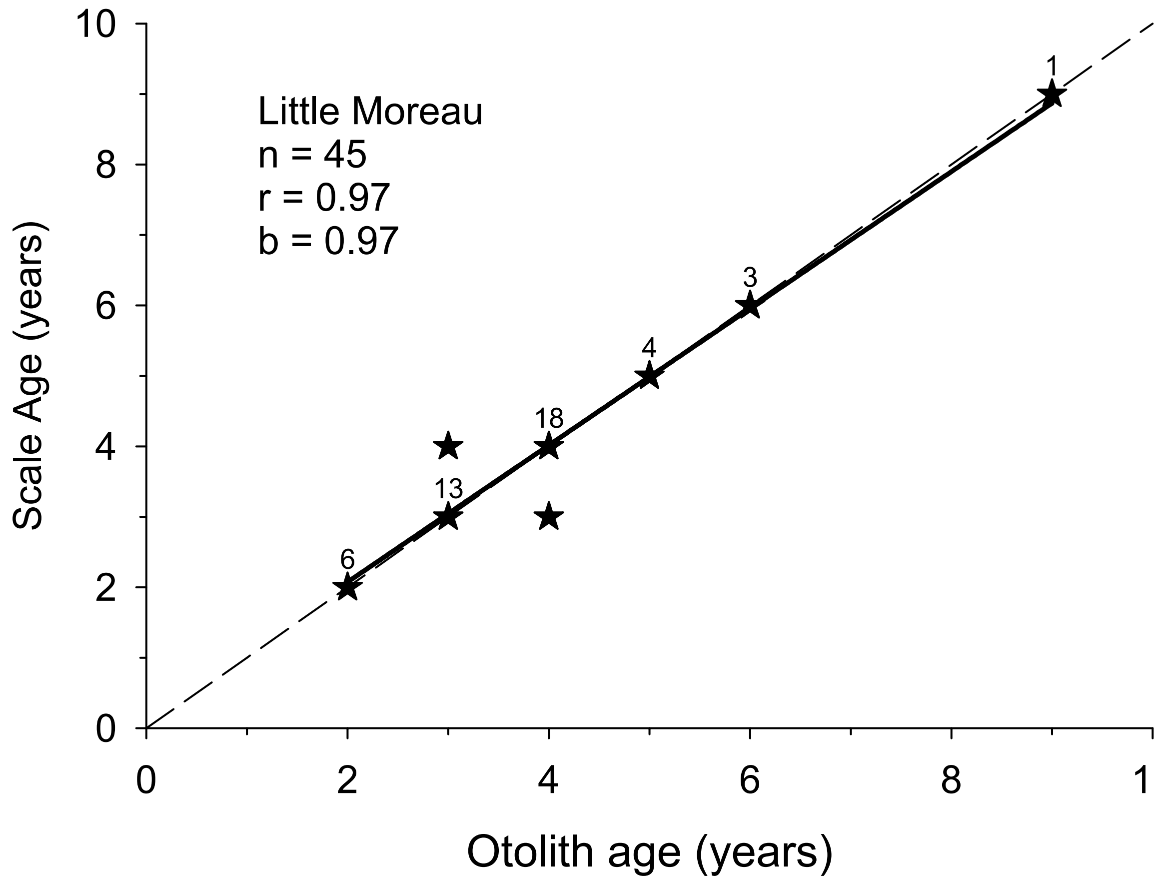

Figure 2-1. Comparison between ages assigned to scales and otoliths for bluegills collected from Little Moreau Lake, South Dakota, June 2004. Numbers above each filled circle represent the number of fish per otolith age group. The correlation coefficient is for a linear relationship. The dashed line indicates the 1:1 relationship (complete agreement), while the solid line depicts the observed relationship.

The Lake Louise population sample (N=59) had a more extended age structure from ages 2 through 11, and 29% of the fish were age 6 or older (Figure 2-2). We found high agreement between scale and otolith age assignments for ages 2-5; only three disagreements occurred for these 32 fish. However, scale ages were consistently lower than otolith ages for age-6 and older bluegills. Scale ages were as much as 5 years lower than otolith ages for these older fish.

For the young bluegill population in Little Moreau Lake, we found little difference in age structures between the two aging methods (Figure 2-3). For the older bluegill population in Lake Louise, age structures did differ between the two aging techniques (Figure 2-4).

Discussion

Scales provided age assignments similar to those from sagittal otoliths over the first 5 years of bluegill lifespan in our two study populations. If we accept the premise that otoliths provide more accurate (Hales and Belk 1992) and more precise (Hoxmeier et al. 2001) age estimates than scales, then ages assigned to scales were consistently underestimated for older bluegills during our study. Thus, our results corroborate the recommendation by Hales and Belk (1992) that whole otoliths be used for bluegill aging through age 4 (their study) or 5 (our study), with cracked and sanded otoliths being used for older fish. In addition, recruitment patterns appeared more consistent with the scales ages, but more erratic with the presumably more accurate otolith ages. As a result, interpretation of recruitment (i.e., year-class strength) would be incorrect when conducted with less accurate scale age determination. Thus, when accurate age-structure assessment or mortality rate determination is required, we recommend that South Dakota bluegill populations be aged with sagittal otoliths. For an assessment of growth rates over the first several (i.e., up to age 4 or 5) years of life, scale ages likely will be satisfactory.

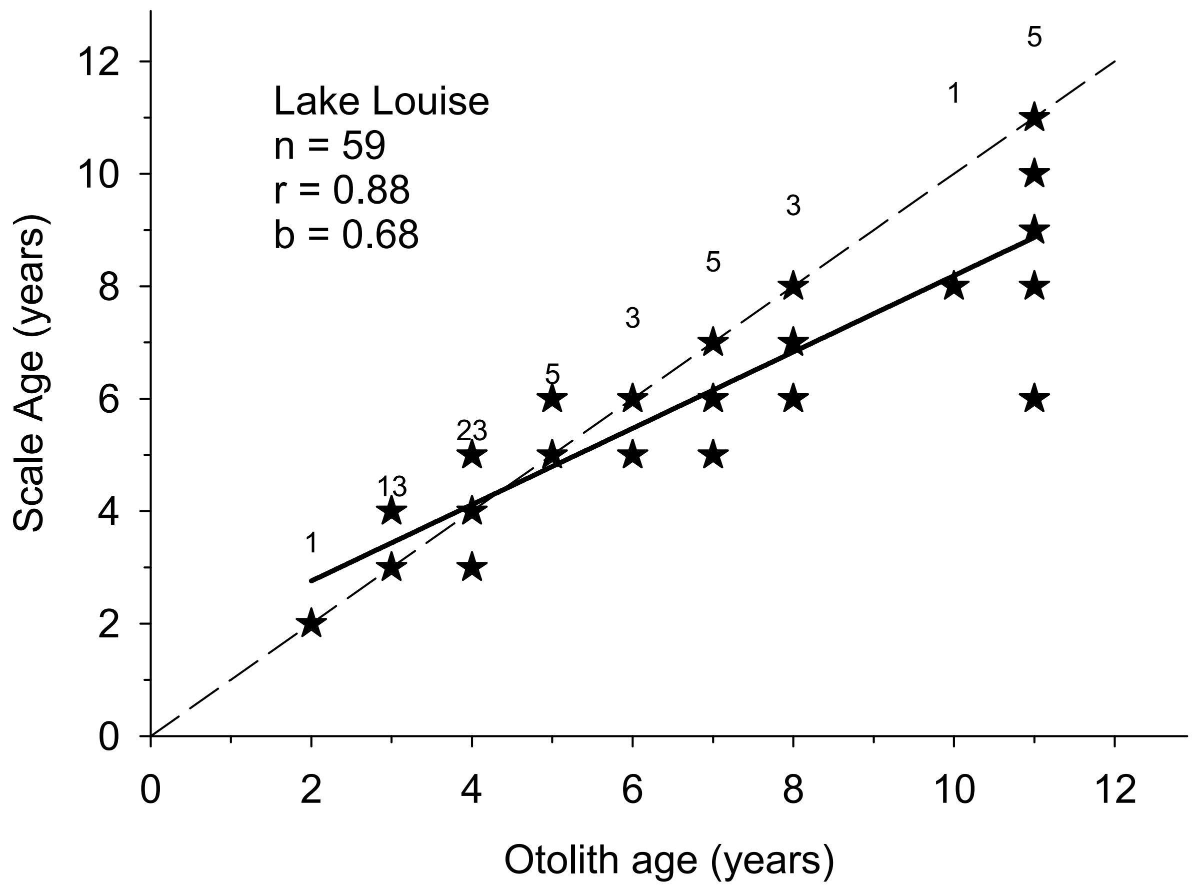

Figure 2-2. Comparison between ages assigned to bluegill scales and otoliths for fish collected from Lake Louise, South Dakota, June 2004. Numbers above each filled circle represent the number of fish per otolith age group. The correlation coefficient is for a linear relationship. The dashed line indicates the 1:1 relationship (complete agreement), while the solid line depicts the observed relationship.

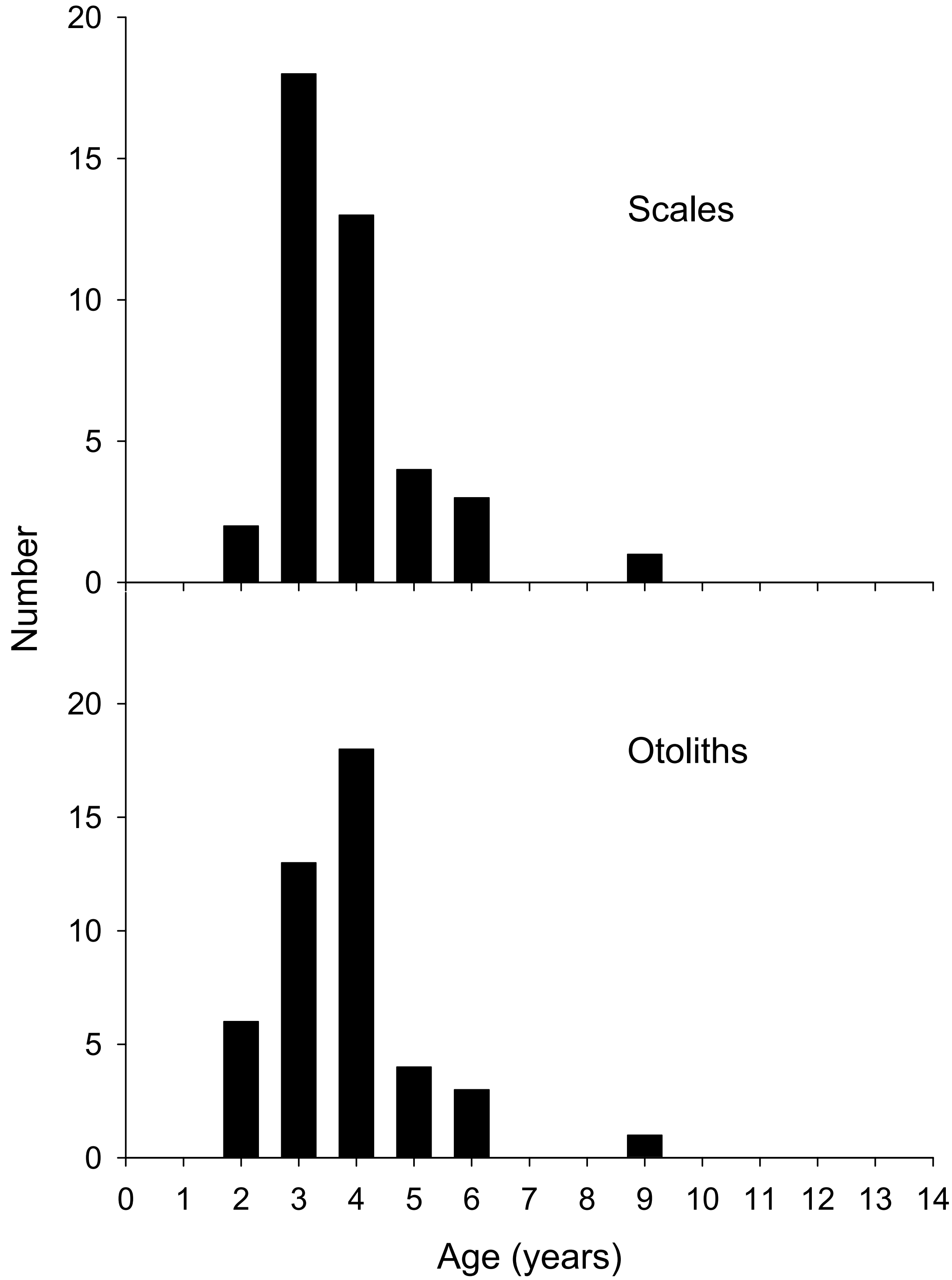

Figure 2-3. Bluegill age structure based on scales (top) and otoliths (bottom) for fish (N=45) collected from Little Moreau Lake, South Dakota, June 2004.

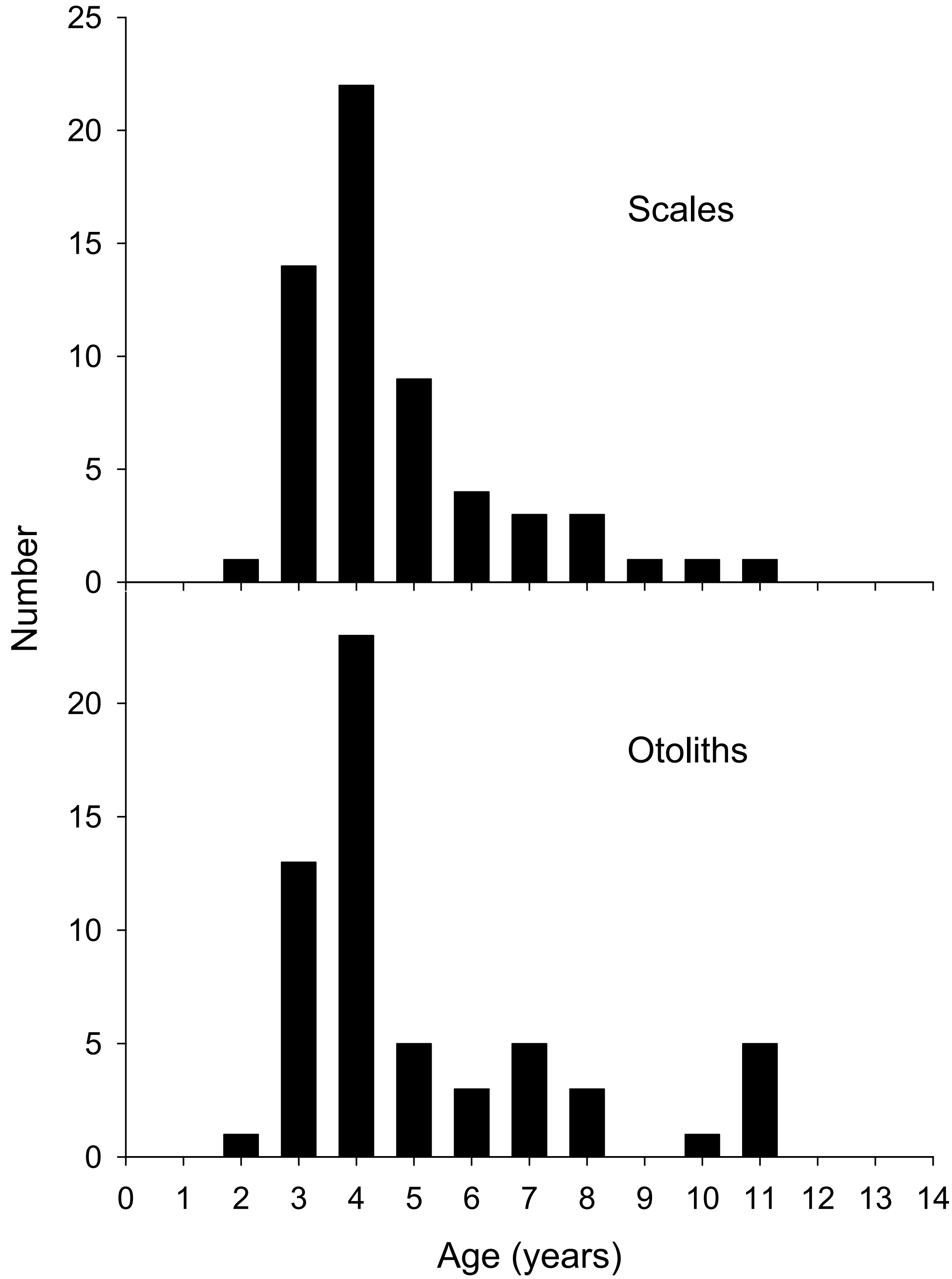

Figure 2-4. Bluegill age structure based on scales (top) and otoliths (bottom) for fish (N = 59) collected from Lake Louise, South Dakota, June 2004.

CHAPTER 3. ASYNCHRONOUS BLUEGILL RECRUITMENT IN FOUR SOUTH DAKOTA IMPOUNDMENTS

Introduction

Year-class strength is set early in life for many, but not all, fishes. Abiotic processes can affect recruitment during this critical time period, including factors such as water temperature (Clady 1976), wind/wave action (Aalto and Newsome 1993), precipitation (Pope et al. 1996), dissolved oxygen (Moore 1942), and turbidity (Campbell and Branson 1978). Further, broad scale climatic factors may cause fish populations to recruit in synchrony over an extensive geographic range (Ranta et al. 1995). The objectives of this study were to determine the extent of synchrony in bluegill recruitment patterns in four small South Dakota impoundments, and to assess potential relations between bluegill recruitment and climatic mechanisms (i.e., temperature, precipitation and winter severity).

Methods

Adult bluegills were collected in the summer of 2004 from four South Dakota impoundments. Lake Louise (Hand County) has a surface area of 66 ha and a maximum depth of 7.6 m, Little Moreau Lake (Dewey County) has a surface area of 15 ha and a maximum depth of 6.1 m, Lake Mitchell (Davison County) has a surface area of 273 ha and a maximum depth of 8.8 m, and East Vermillion Lake (McCook County) has a surface area of 223 ha and a maximum depth of 7 m. Lake Moreau is in north-central South Dakota, Lake Louise is in the central part of the state, and Lakes Mitchell and East Vermillion are in southeastern South Dakota. The linear distance from Little Moreau Lake to East Lake Vermillion is 340 km.

We used trap (modified-fyke) nets with a bar mesh size of 19 mm, which retained bluegills as small as 70 mm total length (TL). Bluegills were measured for TL (mm) and sagittal otoliths were then removed from each fish as described by Secor et al. (1991). Otoliths were aged in whole view through age 5 (Hales and Belk 1992; Edwards et al. 2005). Otoliths from age-6 and older bluegills were cracked, wet sanded, placed in clay, and viewed with a fiber optic light under a binocular microscope at 40X magnification after immersion oil was applied.

For each age group present in our four study lakes, we quantified the relative strength or weakness of each cohort using the residual method (Maceina 1997) which is based on linear regression of number as a function of age (i.e., the same data set as a catch-curve analysis). A positive residual indicates a stronger year class while weaker year classes are indicated by negative residuals. The extent of recruitment synchrony among populations was assessed with correlation analysis of residuals (i.e., year-class strength indexes) by lake pairs. Next, variability in year-class strength within lakes was related to climate metrics. Based on prior research, we developed six *a priori* models to describe variability in bluegill recruitment using precipitation (cumulative total precipitation from April through October), temperature (cumulative temperature [ºC] from April through October), and a winter severity index (number of days below 0°C from October through April during the first winter for each bluegill year class). Climate data were obtained from the National Oceanic and Atmospheric Administration monitoring station nearest to each lake. We utilized Akaike's information criterion (AICc, corrected for small sample size) to choose the most supported model(s) from our set of candidate models (Burnham and Anderson 1998).

Results

Age-structure analysis indicated that age-2 and older bluegills were collected from all four impoundments (Figure 3-1); the lack of age-1 bluegills likely is a result of the mesh size (19-mm bar) on our sampling gear. Lake Louise had the most bluegill age groups present in our sample (ages 2-11) and contained the oldest fish captured in our samples. The Louise bluegill population was dominated by the 2000 (age 4) and 2001 (age 3) year classes. The Little Moreau Lake bluegill population sample also was dominated by the 2000 and 2001 year classes. The Lake Mitchell sample contained bluegills to age 10, while the East Lake Vermillion sample included bluegills to age 8. The East Vermillion Lake population sample was dominated by the 2000 cohort.

Correlation analysis indicated that recruitment patterns were not similar between lakes; all between-lake correlations of the year-class strength indices (i.e., residuals) were nonsignificant (Table 3-1). In fact, the highest correlation coefficient was linked to a negative relation between two populations ($r = -0.76$; Lakes Louise and Little Moreau), which is opposite of the expected positive correlation that would indicate similarity in recruitment patterns. Thus, based on our 340-km scale in impoundment geographic locations, we found no apparent landscape level recruitment patterns among populations that would indicate synchronous recruitment among systems.

Our information-theoretic assessment of the potential relation of climate to bluegill recruitment indicated that *a priori* models based individually on April through October total precipitation, April through October air temperature, and winter severity were more supported than combinations of these individual metrics (Table 3-2). In addition, all three individual metrics were quite similar in their support. Thus, based solely on this analysis of climate variables, we did find some support for the concept of climatic influence on bluegill recruitment. However, *post hoc* analyses of relations between year-class residuals and the three climate metrics revealed low correlation coefficients ($r = 0.07$ for temperature, $r = -0.07$ for winter severity, and $r = 0.10$ for precipitation).

Discussion

Bluegill recruitment patterns thus were asynchronous in four South Dakota impoundments. We found no evidence of broad environmental influences similarly affecting recruitment among waters as did Phelps (2006) for common carp *Cyprinus carpio* in eastern South Dakota lakes. Synchronization of animal population dynamics (i.e., recruitment, growth, and mortality) in relation to climatic variation is referred to as the “Moran effect” (Moran 1953). Relatively few studies have assessed the Moran effect for freshwater systems, but some such work has been completed (e.g. Koonce et al. 1977; Pope et al. 1997; Schupp 2002).

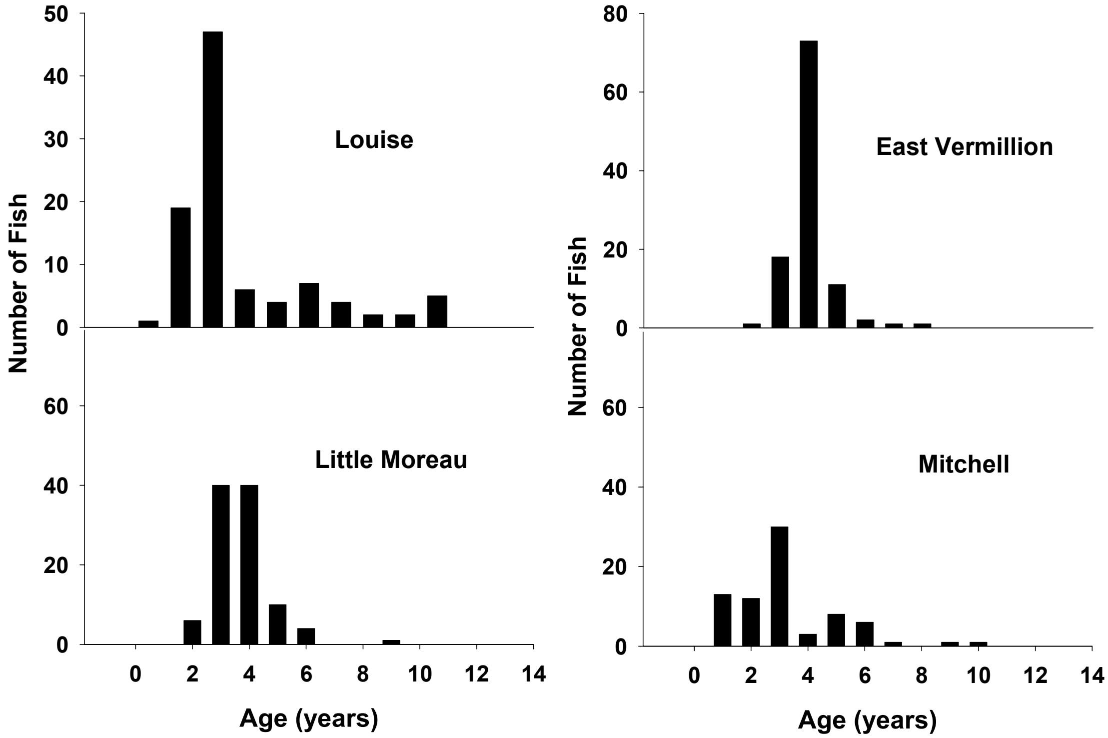

Figure 3-1. Age-frequency distributions for bluegill population samples collected from four South Dakota impoundments using modified-fyke nets during summer 2004.

Table 3-1. Between-lake correlation analysis for bluegill recruitment patterns in four South Dakota impoundments. A higher correlation coefficient indicates more synchrony in year-class strength between those two populations. N is the number of year classes (i.e., cohorts) that were present in both population samples.

Correlation	**N**	**r**	**P**
Little Moreau * East Vermillion	5	0.52	0.37
Louise * East Vermillion	6	0.02	0.96
Mitchell * East Vermillion	5	0.24	0.69
Louise * Little Moreau	5	-0.76	0.14
Mitchell * Little Moreau	5	-0.06	0.92
Mitchell * Louise	5	0.34	0.57

Table 3-2. Akaike's information criteria values relating bluegill recruitment indexes with climatological variables. Temp = ambient April through October temperature; Precip = April through October total precipitation; Wint = winter severity index (see text for complete determination of abiotic variables).

***A priori* models**	**N**	**K**	**AICc**	**Delta AICc**	**Wi**
Precip	26	3	-31.92	0	0.29
Temp	26	3	-31.80	0.13	0.27
Wint	26	3	-31.80	0.13	0.27
Precip + Temp	26	4	-29.22	2.70	0.08
Temp + Wint	26	4	-29.11	2.82	0.07
Precip + Temp + Wint	26	5	-26.26	5.67	0.01

Bluegill recruitment was positively related to ambient temperature and precipitation during April-October, and negatively related to winter severity in our four study impoundments. However, all relations were weak. Thus, we suggest that biotic factors such as competition (Werner and Hall 1979) and predation be further explored to more fully understand bluegill recruitment patterns in South Dakota impoundments. Santucci and Wahl (2003) found that earlier-spawned bluegill cohorts actually had higher mortality than those spawned later, which they attributed to predation by largemouth bass. They also reported little evidence of size-selective overwinter mortality for age-0 bluegills, unlike studies at more northerly locations. Bluegill recruitment was related to bluegill larval abundance in water bodies without predators (Beard 1982), but not related to larval abundance in waters with predators (Cargnelli and Gross 1996; Partridge and DeVries 1999).

CHAPTER 4. INTERANNUAL VARIATION IN BLUEGILL SPAWNING PERIODICITY IN SOUTH DAKOTA IMPOUNDMENTS

Introduction

The bluegill is typically considered a colonial, multiple-spawning fish. The expected, extended spawning season was observed in Crane Lake, Indiana, where larval bluegills were collected from early June to early September (Werner 1969). Garvey et al. (2002) reported two peaks in inshore densities of larval bluegills, once in late June and again in late July, in Lake Opinicon, Ontario. Beard (1982) reported bluegill spawning durations from 31 d to 112 d in three Wisconsin lakes. Understanding how these differential durations in reproduction influence reproductive success of bluegill could provide valuable information into the population dynamics not only of bluegill and but also for sympatric largemouth bass that may depend on bluegill for a prey source.

In fish populations that experience size-selective, over-winter mortality, both hatching period and growth may be important determinants regulating recruitment to the following spring. Previous studies have indicated that later-hatched bluegills had higher survival than their earlier-hatched counterparts (Garvey et al. 2002; Santucci and Wahl 2003). Partridge and DeVries (1999) reported that earlier-hatched cohorts of bluegill in two experimental ponds had faster growth rates than later-hatched cohorts and they suggested that density-dependent factors likely regulated daily growth and subsequent survival. Little information is available on bluegill reproductive biology in South Dakota impoundments. Therefore, the objectives of this study were to 1) assess the extent and duration of bluegill spawning and 2) describe bluegill hatch timing, hatch duration and daily growth rates across years and among populations in four South Dakota impoundments.

Methods

Sampling was conducted at four impoundments located in eastern South Dakota during the summers of 2005 and 2006. Lake Alvin is a 42-ha impoundment located in Lincoln County and has a maximum depth of 7.2 m and a mean depth of 2.9 m. Lake Marindahl is a 62-ha impoundment located in Yankton County and has a maximum depth of 9.5 m, with a mean depth of 3.7 m. Lake Louise is a 64-ha impoundment located in Howard County and is the farthest west impoundment in this study; maximum depth is 6.5 m and mean depth is 2.3 m. Lake Mitchell is located in Davison County and is largest of the impoundments included in this study at 271 ha; maximum depth is 7.3 m and mean depth is 3.7 m.

Larval bluegills were collected from the four study impoundments with a 0.75-m diameter ichthyoplankton surface trawl (1,000-μm bar mesh) fitted with a flow meter to quantify the volume of water filtered. Samples were collected from early June through mid September during 2005 and 2006. Trawl duration was 3-5 min at an estimated speed of 1.75 m/sec, which was the fastest speed possible while keeping the trawl submerged in the water. All samples were preserved in 70% ethanol until processed. Larval fishes were identified to genus and total length was measured to the nearest millimeter.

Sagittal otoliths were removed from up to 30 fish per sampling date from each impoundment to obtain estimates of hatching date and daily growth. Otoliths were wiped clean and then mounted on microscope slides with cyanoacrylic cement. Prepared otoliths were viewed under a 400X magnification microscope that projected images to a television monitor to aid in the enumeration of daily rings. Counts were conducted by two independent readers; if counts were within 5 d the counts were averaged. If disparity was greater than 5 d, a third experienced reader was consulted and a concert read was conducted until all readers agreed upon an age. When all readers could not come to a consensus the otolith was removed from the data set.

Garvey et al. (2002) confirmed that bluegill daily ring counts corresponded to days post hatching, and that swim-up occurred approximately 3 d post hatching. In addition, bluegills were 5-6 mm standard length at time of hatching. Therefore, hatching date for individual fish in my study was calculated by subtracting the number of daily rings from the sampling date and then subtracting 3 d. Daily growth was calculated by subtracting the estimated length of bluegill at time of hatch (5 mm) from the length of the fish at time of capture, and then dividing by the number of daily rings, after subtracting 3 d.

Results

Larval abundances

Peak larval bluegill abundances were highly variable among impoundments during both years. In the summer of 2005, larvae were first collected on 14 June and last detected on 17 August (Figure 4-1). Peaks in mean larval abundances ranged from 12 to 49 larvae/100 m^3, were primarily unimodal in all impoundments and peaked in late June or early July (Figure 4-1). Lake Louise had the lowest larval abundance of all the impoundments in 2005 with a peak larval abundance of 12 larvae/100 m^3. The highest level of abundance documented was a mean of 49 larvae/100 m^3 at Lake Mitchell. Larval abundances in our study impoundments were relatively low when compared to those reported in other studies (Table 4-1). Our density estimates were likely underestimated because we only sampled the top 0.75 m of the water column and head pressure at the mouth of the net also allows some escapement.

In 2006, larval bluegill production was lower than in 2005 at all impoundments except Lake Mitchell, which experienced the highest larval abundances recorded in this study. Peak larval abundances ranged from 2 to 87 larvae /100 m^3 in 2006 and abundance estimates were multimodal in Lakes Marindahl, Mitchell and Alvin (Figure 4-2). Peaks in abundance estimates occurred in late June and mid August at Marindahl and in mid July and mid August at Alvin. Spawning in Lake Mitchell was much more protracted in 2006 than 2005 with three modes in larval abundance estimates occurring during mid June, July and August. Lake Louise again had the lowest larval abundance in 2006 with a peak abundance of only 3 larvae/100 m^3, which was based on a sample of only seven fish. Due to insufficient sample size, hatching date and daily growth estimates were not calculated for Lake Louise in 2006.

Hatching Dates

Bluegill hatching began in early June in Lakes Mitchell and Marindahl during the summer of 2005; however, Lake Alvin hatching date assessments indicated that spawning was initiated approximately 10 d later (Figure 4-3). Bluegill in Lake Mitchell had much more

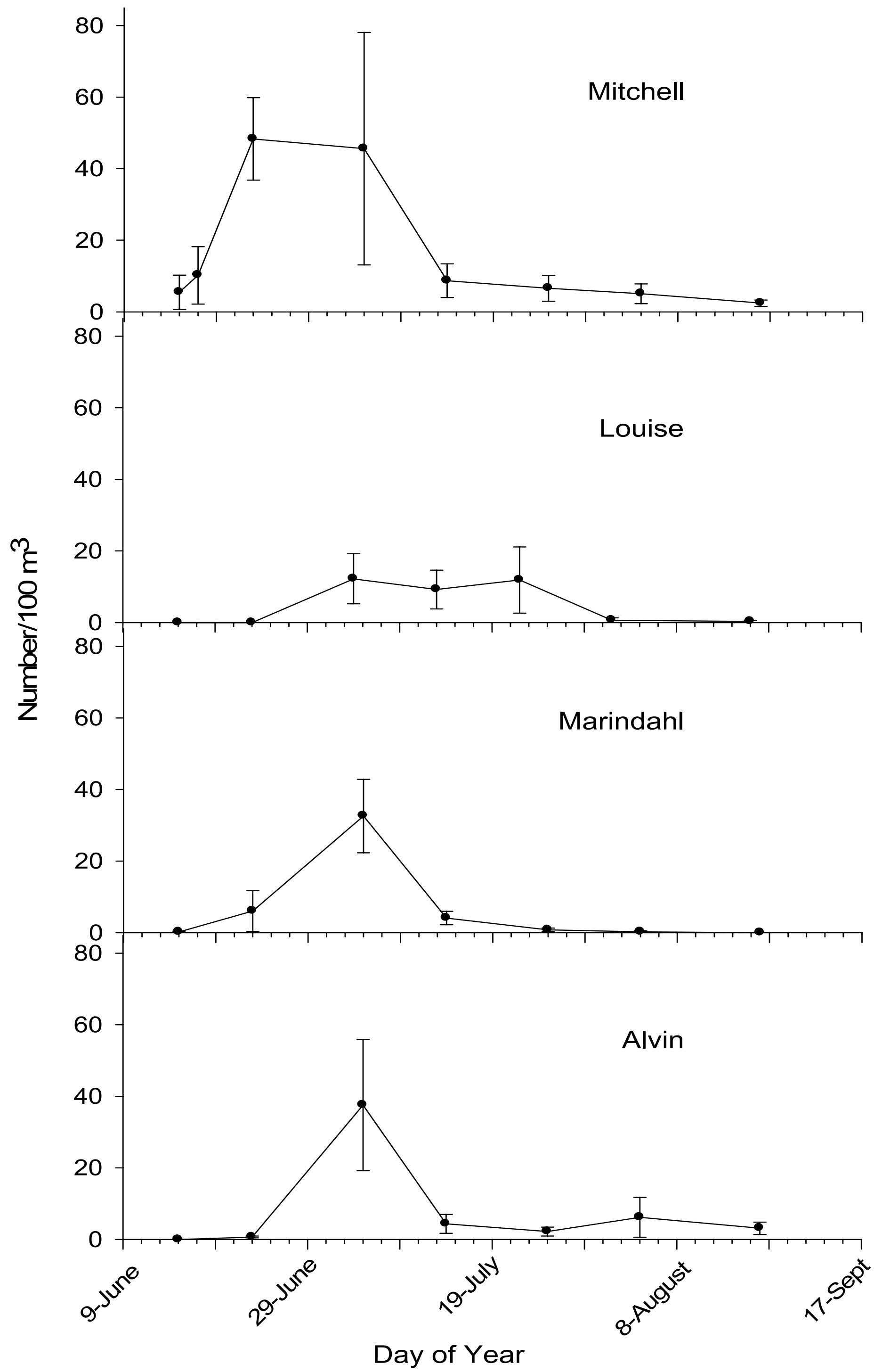

Figure 4-1. Temporal trends in mean larval bluegill abundance (number/100 m^3) in Lakes Mitchell, Alvin, Marindahl and Louise during the summer of 2005. Vertical bar represent $\pm$1 SE.

Table 4-1. Larval bluegill densities (number/m^3) sampled in various geographic locations using a 0.75-m diameter ichthyoplankton net, unless otherwise noted.

Location	Peak abundance (larvae/m^3)	Reference
Ridge Lake, IL*	275.0	Santucci and Wahl 2003
Auburn University ponds, AL**	360.0	Partridge and DeVries 1999
Lake Opinicon, Ontario**	~1.5	Garvey et al. 2002
Cozad Lake, NE	12.5	Chvala 2000
Pelican Lake, NE (1998)	15.8	Chvala 2000
Pelican Lake, NE (2004-2006)	1.4-17.6	J.C. Jolley
Lake Alvin, SD	0.1-0.4	This study
Lake Louise, SD	0.0-0.1	This study
Lake Marindahl, SD	0.01-0.3	This study
Lake Mitchell, SD	0.5-0.9	This study

* Sampled using Miller high speed sampler
** Sampled using 0.5-m ichthyoplankton net

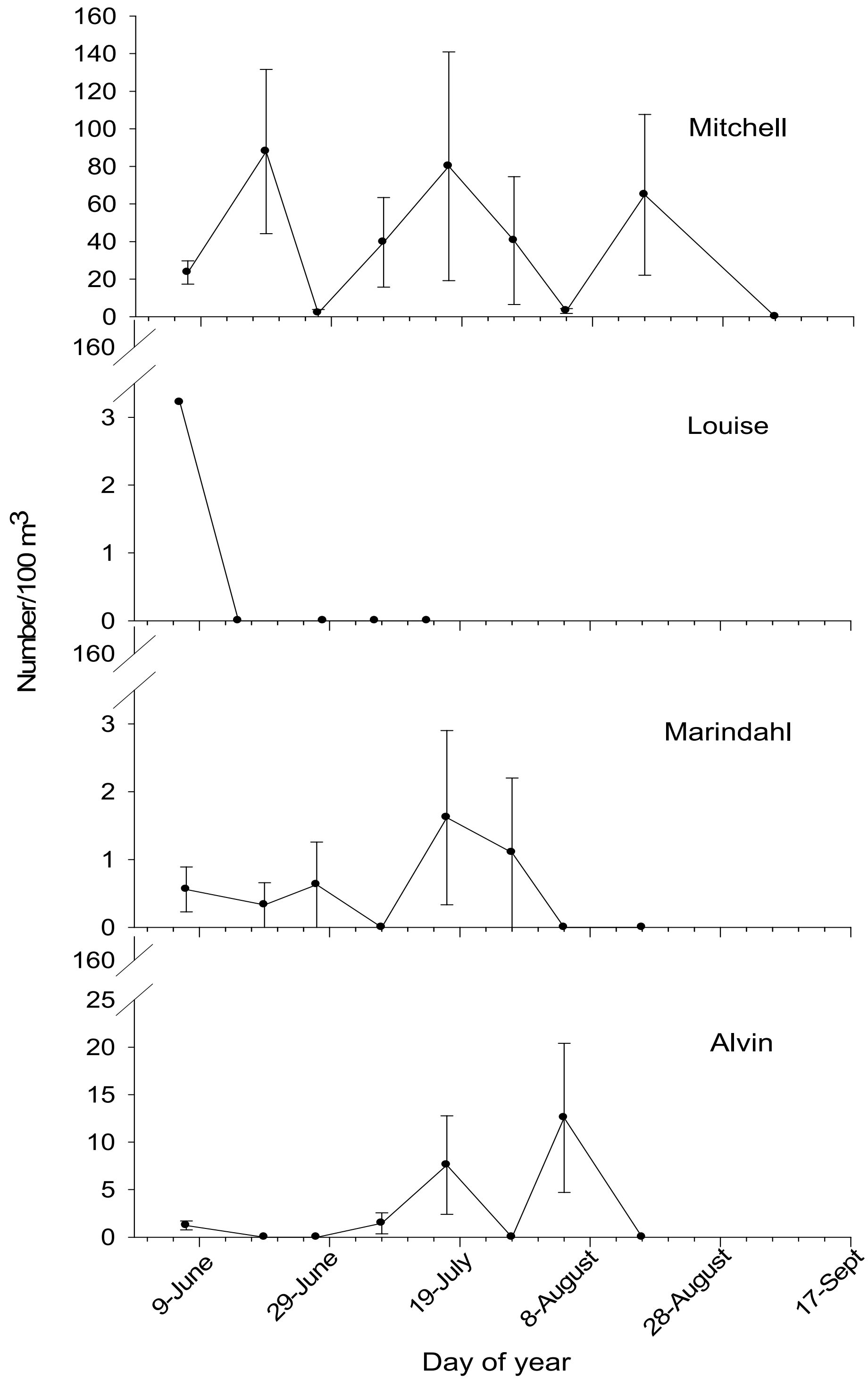

Figure 4-2. Temporal trends in mean larval bluegill abundance (number/100 m^3) in Lakes Mitchell, Alvin, Marindahl and Louise during the summer of 2006. Vertical bar represent $\pm$1 SE.

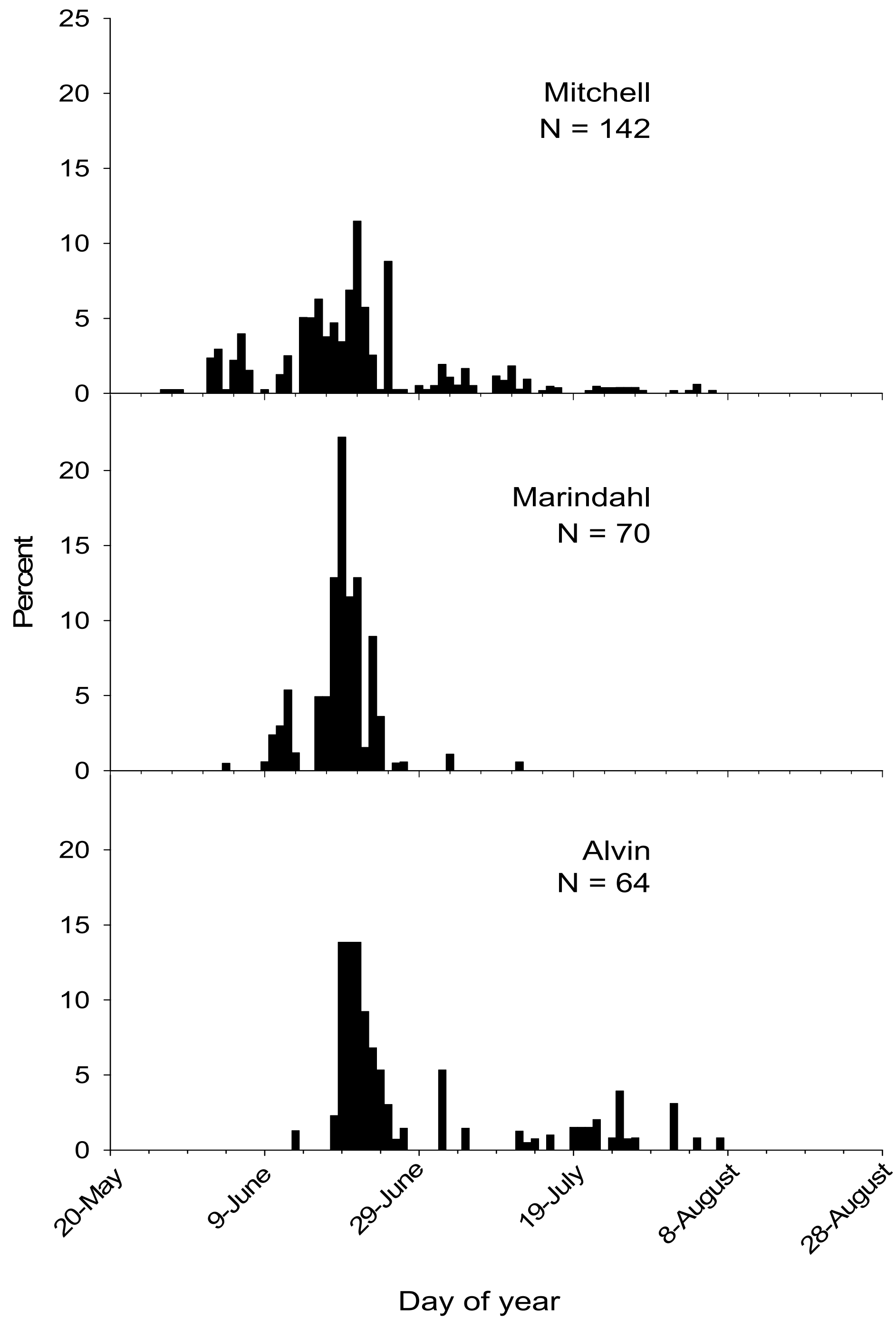

Figure 4-3. Hatching-date distributions estimated from daily otolith ring enumeration for bluegills collected from Lakes Mitchell, Marindahl and Alvin during the summer of 2005.

extended spawning seasons during 2005 and 2006 with hatching durations of 71 and 77 d, respectively (Figures 4-3 and 4-4). In contrast, spawning durations in Lakes Marindahl and Alvin were much shorter both years, with hatching duration estimates of 38-54 d (Figure 4-3 and 4-4).

Tracking individual cohorts

To facilitate determination of bluegill cohorts, length-frequency histograms were constructed for larval bluegills collected each sampling date, by impoundment and by year (Figures 4-5 through 4-11). Length-frequency histograms indicate that three cohorts were produced during the summer of 2006 in Lake Mitchell (Figure 4-11). Marindahl and Alvin also appeared to have multiple modes in larval abundances in 2006 (Figure 4-2) and length frequencies histograms suggest there were two primary cohorts in both impoundments (Figures 4-9 and 4-10). However, during 2005 only one cohort was apparent in all of the impoundments (Figure 4-5 and 4-8).

Daily growth

Mean daily growth rates ranged from 0.22 to 1.08 mm/d during the 2005 growing season (Table 4-2). Bluegills sampled from Lake Louise had the slowest daily growth rates among all the impoundments with growth estimates varying from 0.22 to 0.30 mm/d. Lake Alvin experienced the fastest growth with estimates exceeding 1.0 mm/d. Bluegills collected earliest in Lake Mitchell and Alvin experienced slower growth than those captured later in the season. Conversely, bluegills that were collected earlier in Lake Marindahl in 2005 experienced faster growth than later-collected fish. Once again in 2006, daily growth rates in Lake Alvin were the fastest, exceeding 1.0 mm/d. Daily growth rate estimates from Lake Marindahl in 2006 ranged from 0.42 mm/d to 0.78 mm/d. Bluegills collected early in the spawning season in 2006 from Lake Mitchell displayed faster growth rates than fish collected later in the sampling season. However, in 2006 larval bluegills collected in the later part of the season in Lake Alvin exhibited faster daily growth rates. In 2006, growth rates ranged from 0.40 mm/d to 1.4 mm/d in all the impoundments (Table 4-3). During the duration of this study we found no evidence of density-dependent growth in any of the impoundments (Table 4-4), and no consistent patterns in relation between hatching date and growth rate were evident (Table 4-5).

Discussion

Understanding the mechanisms behind protracted spawning and how this reproductive strategy might influence reproductive success could provide valuable information regarding the population dynamics of that particular species as well as their potential predators. Previous studies have reported that largemouth bass in northern climates can experience substantial overwinter mortality if certain critical stages are not attained before the onset of winter (Gutreuter and Anderson 1985; Miranda and Hubbard 1994a, b; Ludsin and DeVries 1997). Thus, multiple spawning species such as bluegill may provide an extended length range of prey for age-0 and age-1 piscivores, perhaps increasing the growth and subsequent overwinter survival for fishes such as largemouth bass.

Daily growth rates in our impoundments were similar to those reported by other researchers with the exception of Lake Alvin, suggesting that larvae must have had access to

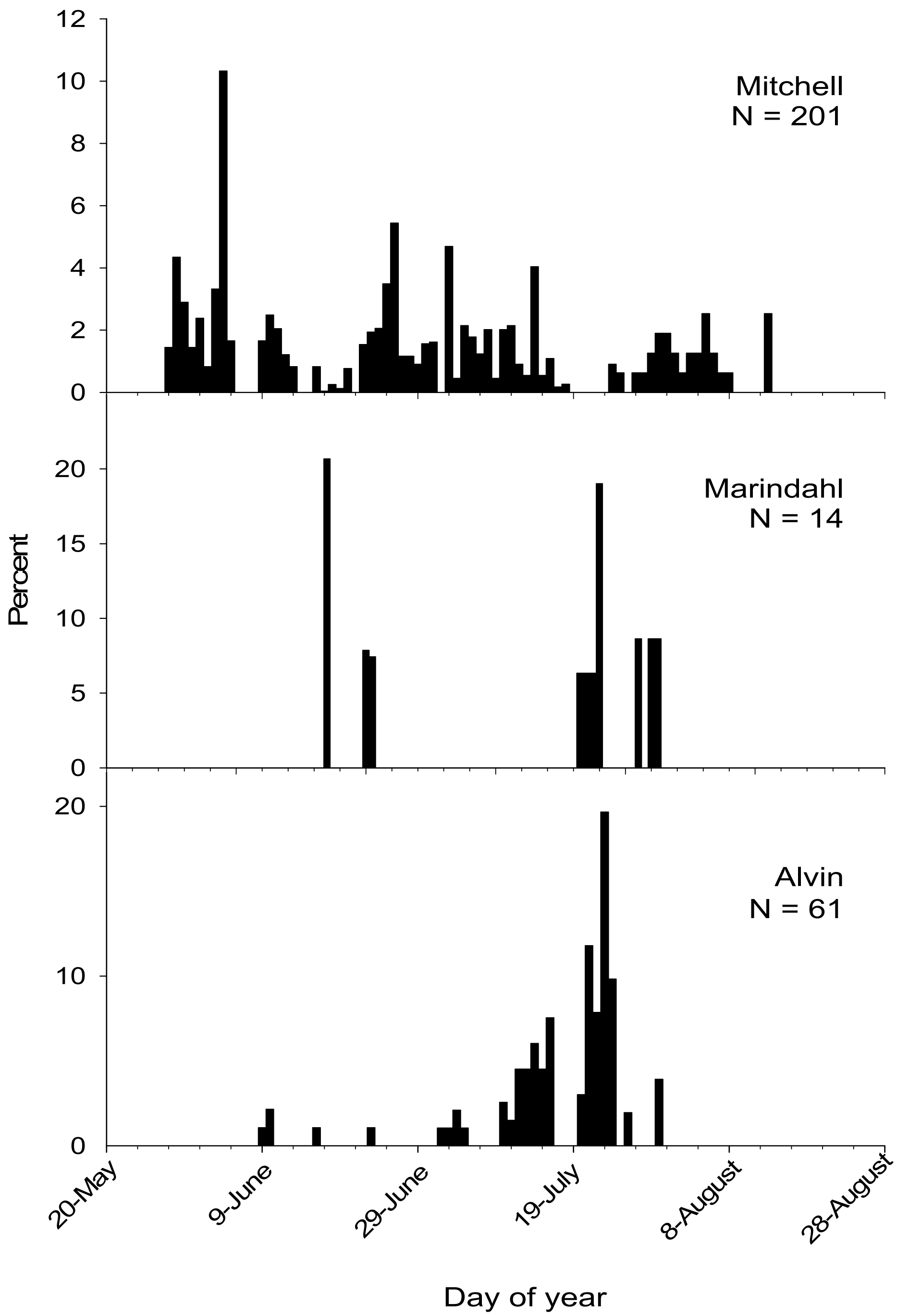

Figure 4-4. Hatching-date distributions estimated from daily otolith ring enumeration for bluegills collected from Lakes Mitchell, Marindahl and Alvin during the summer of 2006.

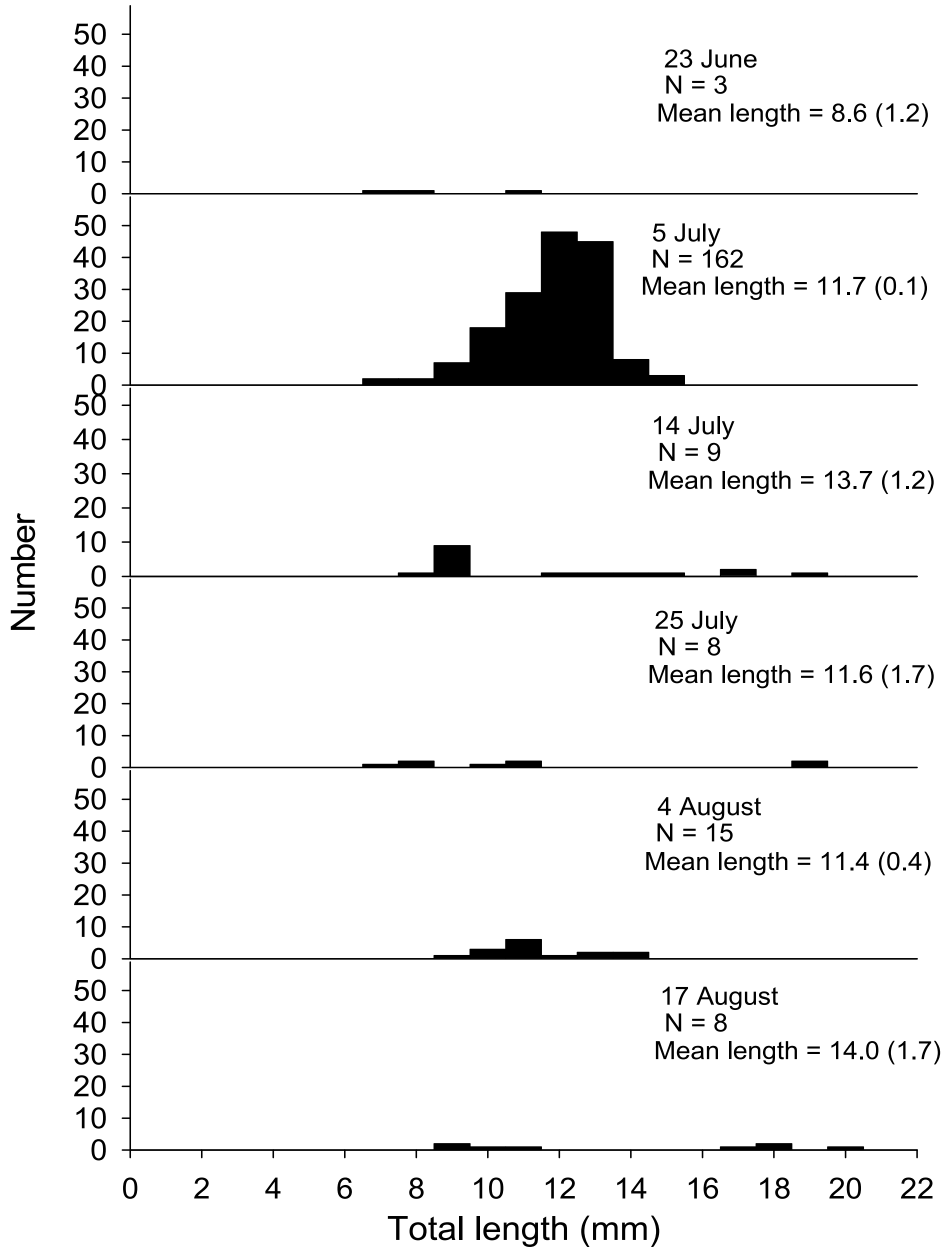

Figure 4-5. Length frequencies for larval bluegills collected from Lake Alvin in surface trawls (four trawls on each date) during 2005. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

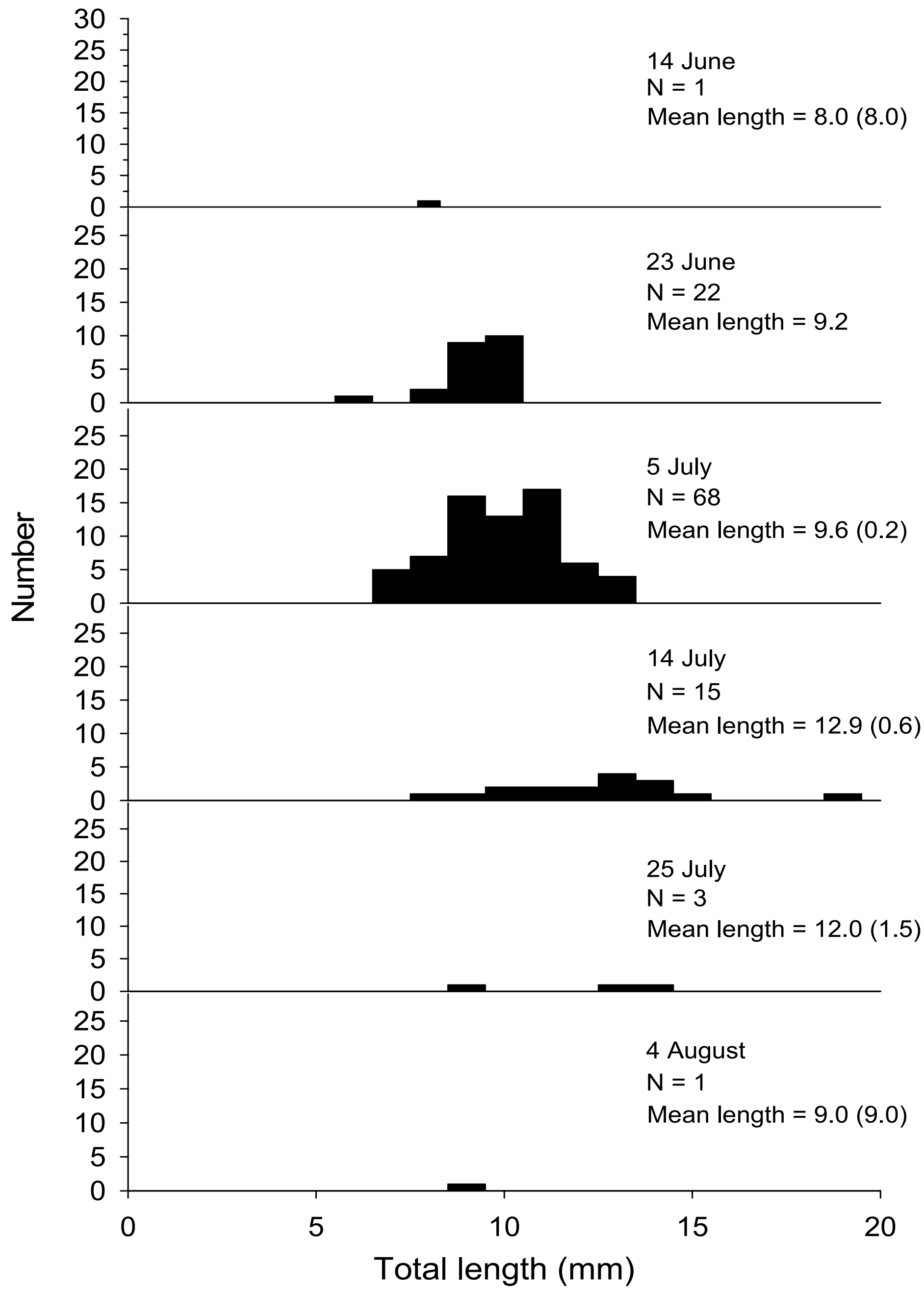

Figure 4-6. Length frequencies for larval bluegills collected from Lake Marindahl in surface trawls (four trawls on each date) during 2005. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

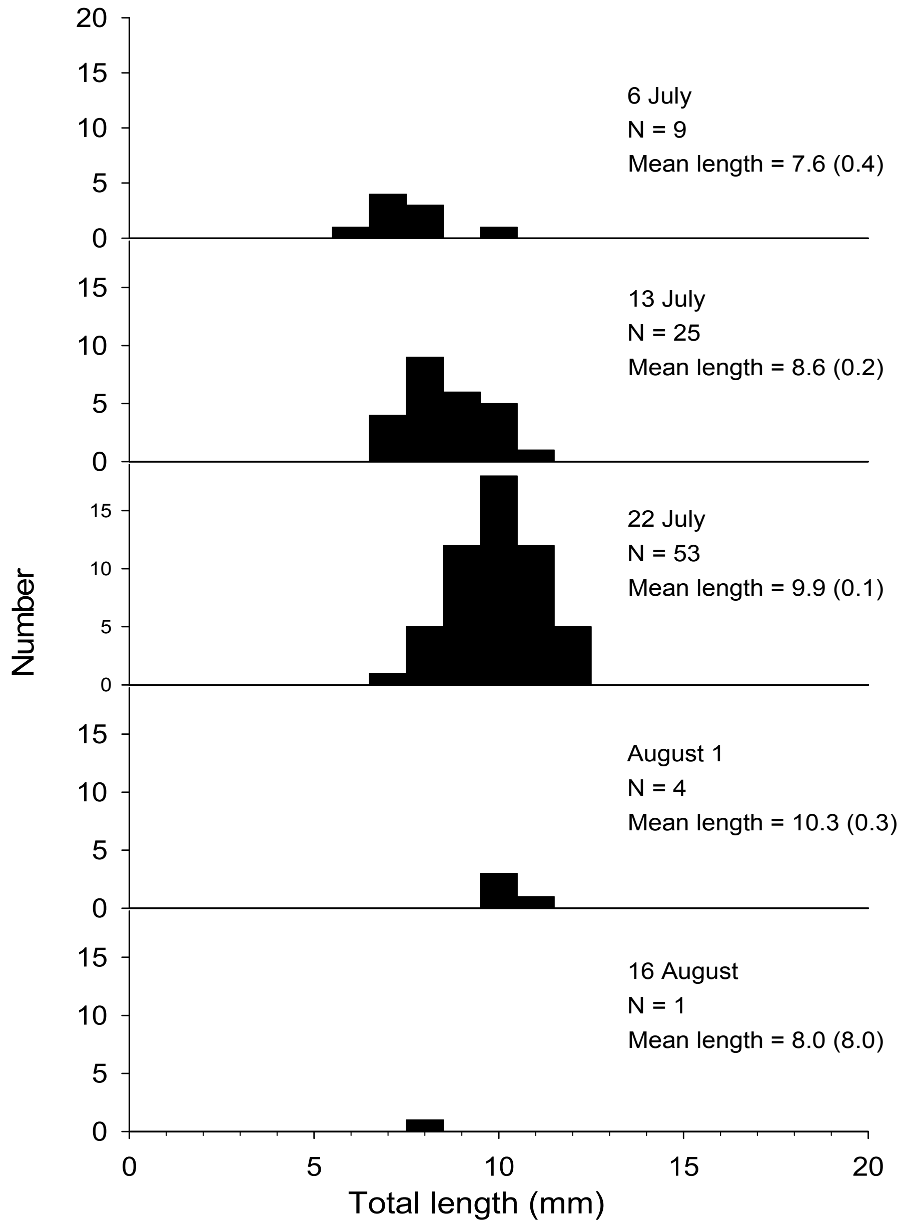

Figure 4-7. Length frequencies for larval bluegills collected from Lake Louise in surface trawls (four trawls on each date) during 2005. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

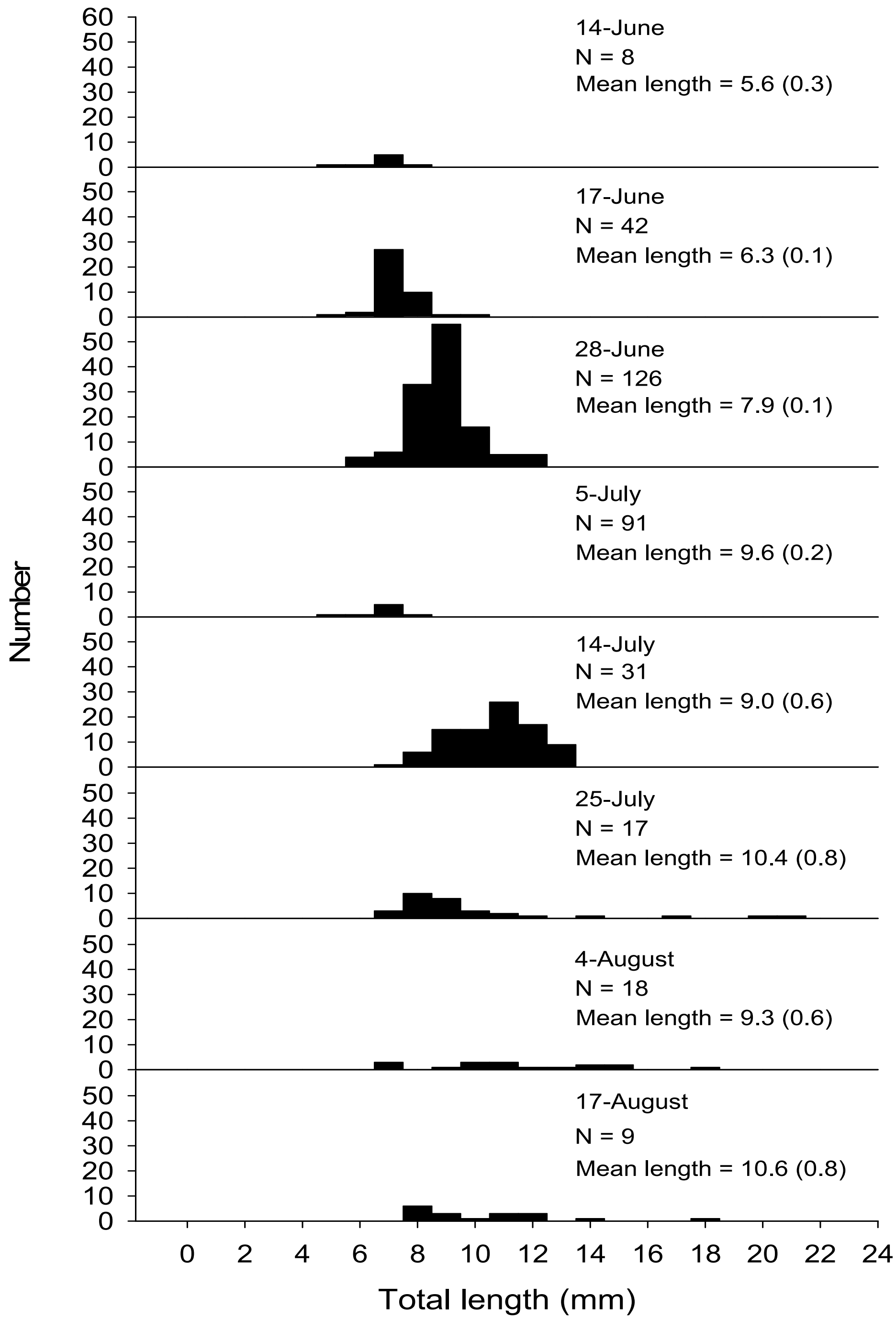

Figure 4-8. Length frequencies for larval bluegills collected from Lake Mitchell in surface trawls (four trawls on each date) during 2005. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

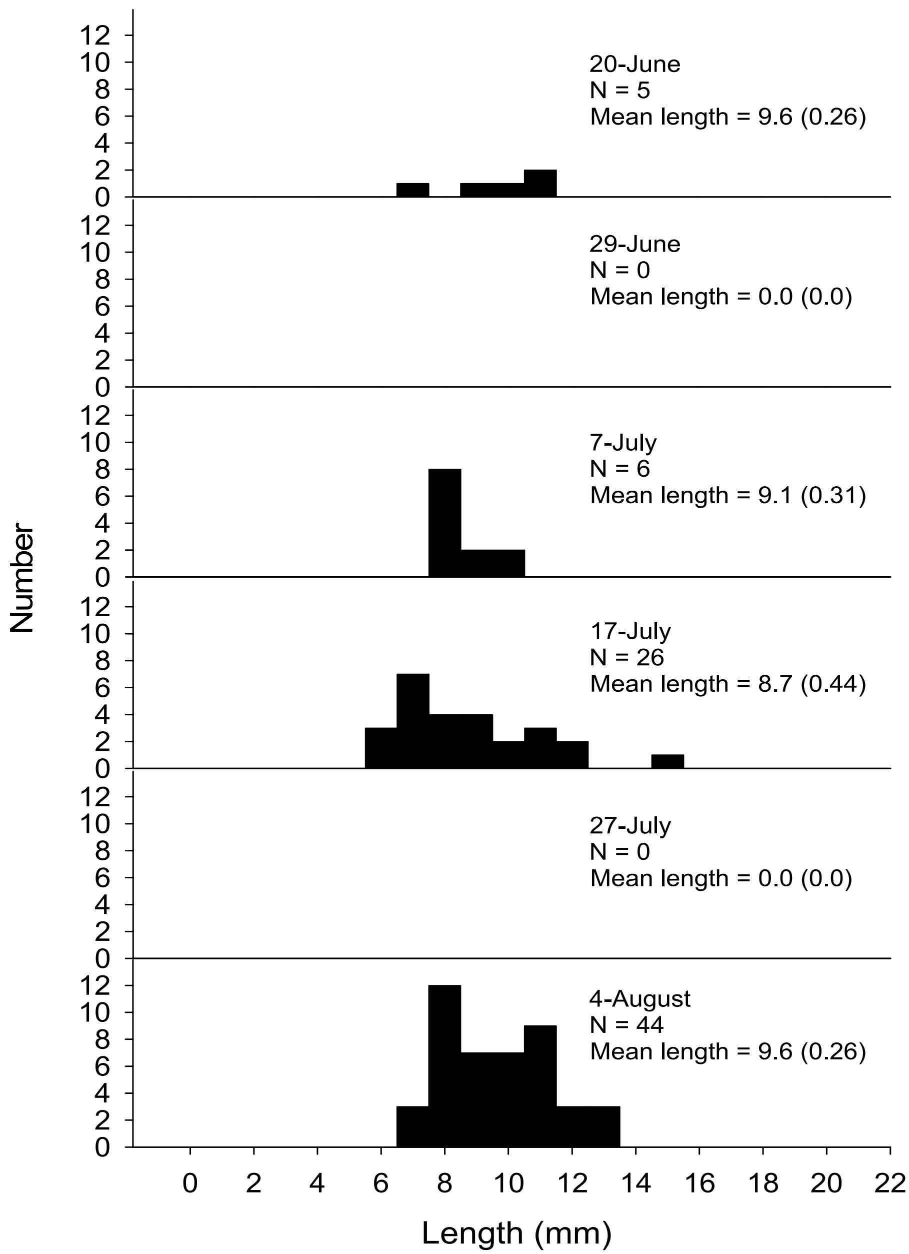

Figure 4-9. Length frequencies for larval bluegills collected from Lake Alvin in surface trawls (four trawls on each date) during 2006. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

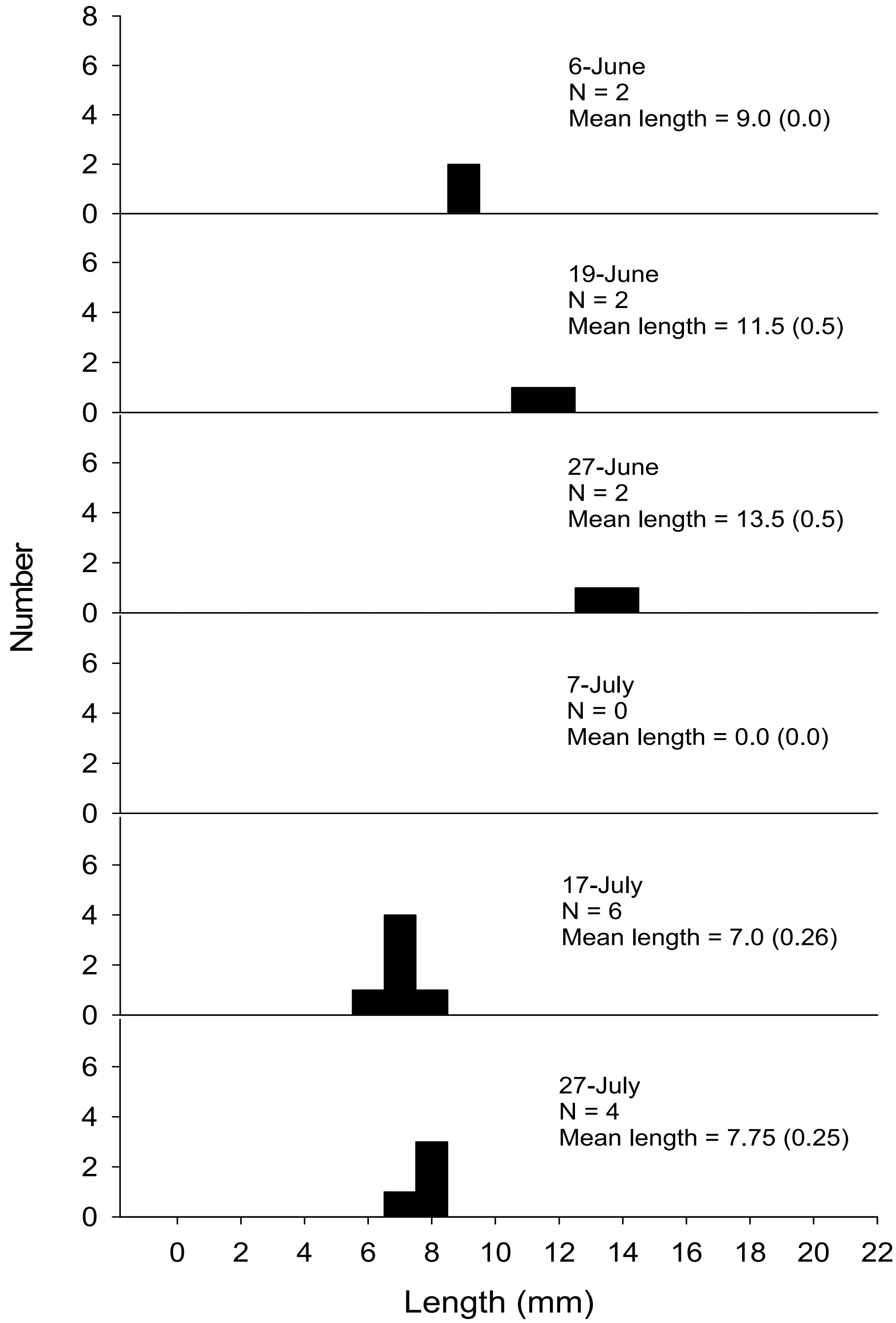

Figure 4-10. Length frequencies for larval bluegills collected from Lake Marindahl in surface trawls (four trawls on each date) during 2006. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

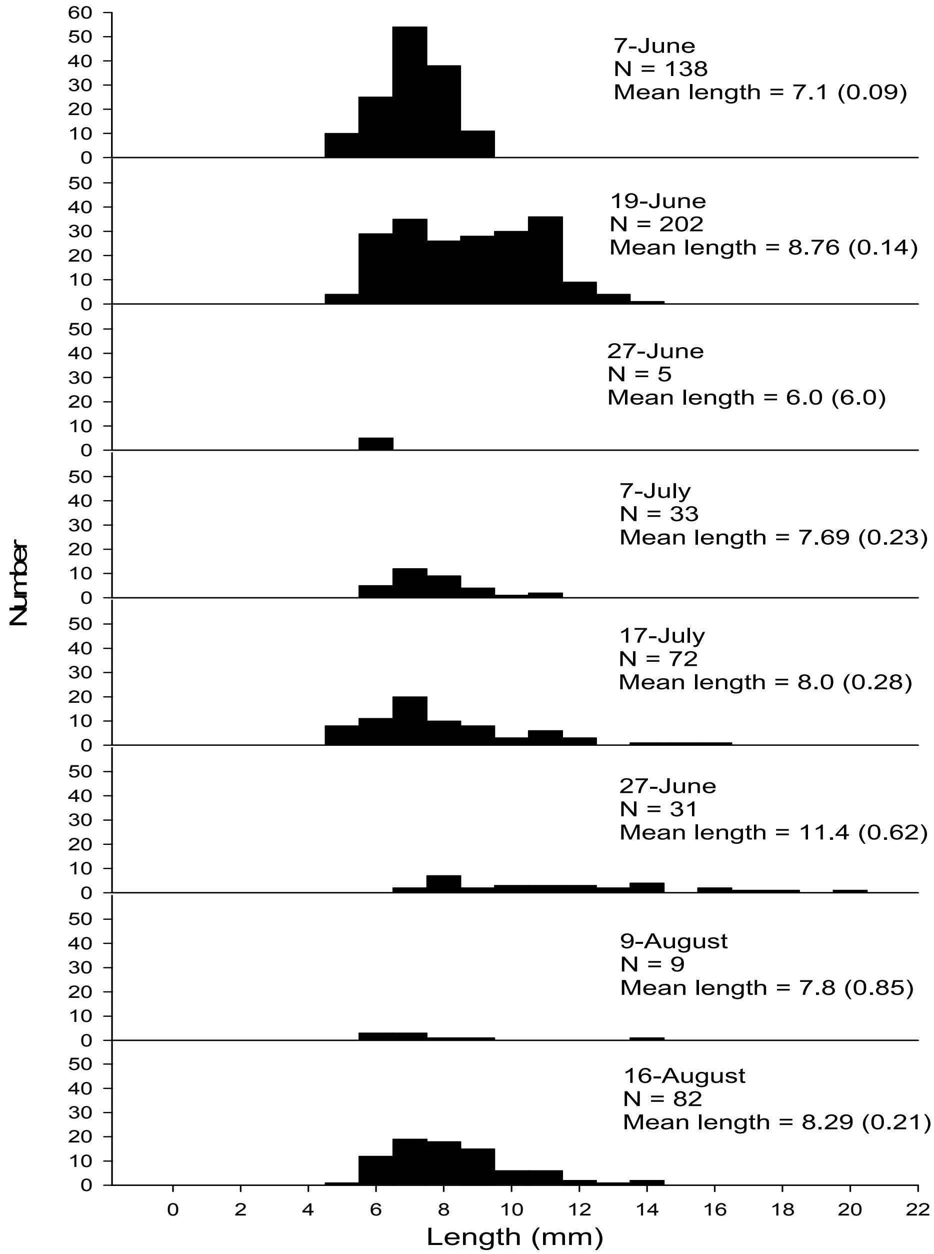

Figure 4-11. Length frequencies for larval bluegills collected from Lake Mitchell in surface trawls (four trawls on each date) during 2006. Total lengths were recorded from each fish collected. Mean length (mm) measurements (with SE in parentheses) are provided for each date.

Table 4-2. Larval bluegill daily growth rate, mean length at capture and larval density (number/100 m^3) in four South Dakota impoundments during the summer of 2005. Standard errors are in parentheses.

Date	N	Daily growth rate	Mean length (mm)	number/100 m^3
Louise				
6-July	8	0.22 (0.03)	7.4 (0.42)	12.21 (7.01)
13-July	22	0.30 (0.02)	8.2 (0.23)	9.22 (5.44)
22-July	30	0.29 (0.02)	9.4 (0.29)	11.88 (9.25)
1-August	4	0.30 (0.01)	10.3 (0.25)	0.66 (0.66)
Mitchell				
14-June	7	0.32 (0.11)	5.6 (0.37)	5.48 (4.8)
17-June	30	0.28 (0.03)	6.6 (0.18)	10.20 (8.03)
28-June	30	0.50 (0.04)	7.9 (0.35)	48.35 (11.55)
7-July	30	0.62 (0.04)	10.1 (0.29)	45.62 (32.49)
14-July	25	0.46 (0.04)	7.8 (0.30)	8.71 (4.70)
25-July	16	0.46 (0.04)	9.5 (0.67)	6.59 (3.62)
4-August	17	0.44 (0.04)	8.8 (0.49)	5.05 (2.74)
17-August	8	0.49 (0.04)	10.0 (0.93)	2.42 (0.89)
Marindahl				
23-June	23	0.83 (0.04)	9.43 (0.27)	6.06 (5.70)
5-July	30	0.56 (0.04)	10.1 (0.30)	32.62 (10.28)
14-July	15	0.54 (0.04)	12.8 (0.60)	4.10 (1.99)
25-July	3	0.46 (0.03)	11.7 (1.9)	0.77 (0.48)
Alvin				
23-June	2	0.50 (0.25)	7.0 (0.0)	0.70 (0.24)
7-July	28	0.85 (0.04)	11.8 (0.37)	37.56 (18.35)
14-July	11	0.87 (0.13)	11.6 (1.15)	4.37 (2.63)
25-July	4	1.08 (0.08)	10.0 (0.91)	2.21 (1.26)
8-August	12	0.99 (0.12)	11.7 (0.47)	6.21 (5.54)

Table 4-3. Larval bluegill daily growth rate, mean length at capture and larval density (number/100 m^3) in four South Dakota impoundments during the summer of 2006. Standard errors are in parentheses.

Lake and date	N	Daily growth rate	Mean length (mm)	number/100 m^3
Mitchell				
7-June	30	0.88 (0.04)	7.1 (0.13)	23.49 (6.21)
19-June	30	0.55 (0.05)	8.8 (0.40)	87.88 (43.71)
27-June	13	0.55 (0.10)	6.7 (0.24)	1.91 (1.91)
7-July	30	0.48 (0.03)	7.7 (0.27)	39.54 (23.83)
17-July	27	0.46 (0.06)	8.3 (0.38)	80.03 (60.86)
27-July	22	0.49 (0.03)	10.0 (0.49)	40.46 (34.0)
4-August	10	0.40 (0.02)	7.8 (0.65)	3.06 (1.31)
16-August	30	0.58 (0.05)	8.3 (0.33)	64.85 (42.78)
Marindahl				
7-June	2	0.75 (0.00)	9.1 (9.1)	0.56 (0.33)
19-June	2	0.50 (0.00)	11.5 (0.5)	0.33 (0.33)
27-June	2	0.42 (0.05)	13.4 (0.5)	0.63 (0.63)
7-July	0	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)
17-July	6	0.78 (0.14)	7.0 (0.25)	1.62 (1.28)
27-July	4	0.62 (0.14)	7.8 (0.26)	1.10 (1.10)
Alvin				
7-June	0	0.47 (0.02)	0.0 (0.0)	0.0 (0.0)
20-June	4	0.00 (0.00)	10.3 (0.5)	1.23 (0.48)
29-June	0	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)
7-July	6	1.19 (0.24)	9.1 (0.3)	1.45 (1.10)
17-July	26	1.13 (0.08)	8.7 (0.44)	7.58 (5.18)
27-July	0	0.00 (0.00)	0.0 (0.0)	0.0 (0.0)
4-August	30	1.40 (0.14)	9.7 (0.26)	12.56 (7.85)

Table 4-4. Correlation analysis between larval BLG mean daily growth by sampling date and larval density on that date at four South Dakota impoundments. N = number of data pairs.

Lake	**Year**	**N**	**r**	**P**
Alvin	2005	5	0.0595	0.9242
	2006	3	0.6992	0.5071
Louise	2005	4	-0.5304	0.4696
	2006	-	-	-
Marindahl	2005	4	-0.0221	0.9780
	2006	5	0.5996	0.2851
Mitchell	2005	8	0.5979	0.1174
	2006	8	-0.0816	0.8478

Table 4-5. Correlation analysis between daily growth for individual larval bluegills and their corresponding hatch date by year and by water body in four South Dakota impoundments. N = number of data pairs.

Lake	**Year**	**N**	**r**	**P**
Alvin	2005	60	0.2331	0.0730
	2006	54	0.3706	0.0058
Louise	2005	61	0.2081	0.1075
	2006	-	-	-
Marindahl	2005	70	-0.3024	0.0110
	2006	15	0.2390	0.3909
Mitchell	2005	147	0.2065	0.0121
	2006	187	-0.2347	0.0014

adequate prey. Our daily growth estimates for Lake Alvin ranged from 0.47 to 1.4 mm/d during both years and we are uncertain as to why growth estimates would be so high that considering lake productivity at Lake Alvin is relatively similar to the other study impoundments (Stueven and Stewart 1996). Warmer water temperatures and density-dependent mechanisms are some factors that may influence growth rates of age-0 bluegill (Krumholz 1949; Latta and Merna 1977). Santucci and Wahl (2003) reported a positive correlation between bluegill daily growth rate and month spawned indicating that fish hatched later in the spawning season had faster growth rates than fish hatched earlier in the year. However, no trends were apparent between daily growth and hatch timing in our study, and density-dependent mechanisms did not appear to be regulating growth in these impoundments.

Bluegill had spawning durations of 35-77 d in our study, which is within the range of 31–112 d reported by Beard (1982) in a Wisconsin lake. Santucci and Wahl (2003) reported that bluegill spawning durations from 87 d to 108 d in an Illinois lake. Apparently spawning duration can be shorter for South Dakota bluegill populations compared to those in more southern climates; whether they always are shorter in South Dakota remains to be determined. Perhaps at northern latitudes environmental conditions rarely provide optimal conditions needed to support extended spawning events.

The differential timing of bluegill spawning in different years during our study might have implications for largemouth bass recruitment. Variability in abundances for age-0 bluegills can influence growth of age-0 largemouth bass (Garvey and Stein 1998). Age-0 largemouth bass tend toward piscivory when possible (Phillips et al. 1995; Mittelbach and Persson 1998) and a fish diet tends to promote faster growth and larger size by the first winter (Keast and Eadie 1985; Bettoli et al. 1992; Olson 1996). As overwinter survival and subsequent recruitment of age-0 largemouth bass often is size dependent (Gutreuter and Anderson 1985; Miranda and Hubbard 1994a, b; Ludsin and DeVries 1997), bluegill spawning duration and timing in South Dakota waters could be linked to largemouth bass recruitment patterns. Future research should assess this potential link between reproduction of the prey species and recruitment of the predator.

CHAPTER 5. SUMMARY AND RESEARCH NEEDS

When assessing population characteristics such as growth, age structure, and mortality rate, it is important that fish ages are accurate. We found that scale ages were similar to ages from otoliths over the first 5 years of the bluegill lifespan; however, ages assigned to scales consistently underestimated ages for older bluegills. Thus, we recommend that sagittal otoliths be used when age structure or mortality rate are being assessed for South Dakota bluegill populations.

We found that bluegill recruitment patterns in South Dakota impoundments functioned on an individual basis and if climatological factors influence those patterns in South Dakota impoundments, then the factors involved likely are complex and interrelated. Therefore, subsequent research should focus on understanding how biotic factors (e.g., predation and competition) influence both bluegill and largemouth bass recruitment in South Dakota impoundments.

Future research will be required to gain more information on the bluegill recruitment process in our four study impoundments. We suggest that quantifying zooplankton densities, monitoring larval bluegill densities, and then assessing juvenile bluegill length at the end of the growing season could provide insight into possible mechanisms regulating recruitment. The extent to which predation affects juvenile bluegill cohorts should also be explored. Fall age-0 and spring age-1 bluegill samples should be collected to assess changes in length-frequency distributions that would provide information on potential size-selective recruitment mechanisms given our relatively northern latitude.

Bluegills are social fishes that exhibit complex mating behaviors and different reproductive strategies that may influence growth rate, and both age and size at maturation. Bluegill reproductive success and eventual recruitment may be related to the age or size at which they mature. Little attention has been given to growth rate and age or size at maturity and how they relate to bluegill spawning periodicity in eastern South Dakota waters. Future research should involve bluegill populations with differing size structures and determine how age or size at maturation and growth rates might influence the extent and duration of bluegill reproduction.

Several studies have reported that the first winter was an important survival bottleneck for largemouth bass. Further, bluegill abundance (i.e., prey supply) has been related to largemouth bass growth and condition. Largemouth bass recruitment can be dependent on several factors, such as total length of the fish at the end of the first growing season, the amount of lipid reserves accumulated by fall, and density of age-0 largemouth bass. However, little is known about the extent and duration of bluegill spawning periodicity and how those might affect largemouth bass recruitment in South Dakota impoundments. Future research should determine growth rates within and among largemouth bass cohorts while monitoring temperature, prey availability, bass and bluegill abundance, and impoundment productivity to provide more insight into bass growth and survival in this northern climate.

REFERENCES

Aalto, S.K., and G.E. Newsome. 1993. Winds and the demic and structure of a population of yellow perch (*Perca flavescens*). Canadian Journal of Fisheries and Aquatic Sciences 50:496-501.

Aday, D.D., C.M. Kush, D.H. Wahl, and D.P. Philipp. 2002. The influence of stunted body size on the reproductive ecology of bluegill, *Lepomis macrochirus*. Ecology of Freshwater Fish 11:190-195.

Beard, T.D. 1982. Population dynamics of young-of-the-year bluegill. Wisconsin Department of Natural Resources, Technical Bulletin 127, Madison.

Beard, T.D., M.T. Drake, J.E. Breck, and N.A. Nate. 1997. Effects of simulated angling regulations on stunting in bluegill populations. North American Journal of Fisheries Management 17:525-532.

Belk, M.C., and L.S. Hales, Jr. 1993. Predation-induced differences in growth and reproduction of bluegills (*Lepomis macrochirus*). Copeia 1993(4):1034-1044.

Bettoli, P.W., M.J. Maceina, R.L. Noble, and R.K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. North American Journal of Fisheries Management 12:509-516.

Burnham, K.P., and D.R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York.

Campbell, R.D., and B.A. Branson. 1978. Ecology and population dynamics of the black bullhead (*Ictalurus melas*, Rafinesque) in central Kentucky. Tulane Studies in Zoology and Botany 20:99-136.

Cargnelli, L.M., and M.R. Gross. 1996. The temporal dimension in fish recruitment: birth date, body size, and size-dependent survival in a sunfish (bluegill:*Lepomis macrochirus*). Canadian Journal of Fisheries and Aquatic Sciences 53:360-367.

Chvala, P.J. 2000. Bluegill reproductive characteristics in Nebraska Sandhill lakes. M.S. thesis. South Dakota State University, Brookings.

Clady, M.D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, *Perca flavescens*. Journal of Fisheries Research Board of Canada 33:1887-1893.

DeVries, D.R., and R.V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland.

Dominey, W. J. 1981. Maintenance of female mimicry as a reproductive strategy in bluegill sunfish (*Lepomis macrochirus*). Environmental Biology of Fishes 6:59-64.

Drake, M.T., J.E. Claussen, D.P. Philipp, and D.L. Pereira. 1997. A comparison of bluegill reproductive strategies and growth among lakes with different fishing intensities. North American Journal of Fisheries Management 17:496-507.

Edwards, K.R., Q.E. Phelps, J.L. Shepherd, D.W. Willis, and J.D. Jungwirth. 2005. Comparison of scale and otolith age estimates for two South Dakota bluegill populations. Proceedings of the South Dakota Academy of Science 84:181-186.

Ehlinger, T.J. 1997. Male reproductive competition and sex-specific growth patterns in bluegill. North American Journal of Fisheries Management 17:508-515.

Garvey, J.E. and R. A. Stein. 1998. Linking bluegill and gizzard shad prey assemblages to growth of age-0 largemouth bass in reservoirs. Transactions of the American Fisheries Society 127:70-83.

Garvey, J.E., T.P. Herra, and W.C. Leggett. 2002a. Protracted reproduction in sunfish: the temporal dimension in fish recruitment revisited. Ecological Applications 12:194-205.

Garvey, J.E., R.A. Stein., R.A. Wright, and M.T. Bremigan. 2002b. Exploring ecological mechanisms underlying largemouth bass recruitment along environment gradients. American Fisheries Society Symposium 31:7-23.

Gutreuter, S.J., and R.O. Anderson. 1985. Importance of body size to the recruitment process in largemouth bass populations. Transactions of the American Fisheries Society 114:317-327.

Guy, C.S., and D.W. Willis. 1990. Structural relationships of largemouth bass and bluegills in South Dakota ponds. North American Journal of Fisheries Management 10:338-343.

Guy, C.S., and D.W. Willis. 1991. Relationships between environmental variables and density of largemouth bass in South Dakota ponds. South Dakota Academy of Science 70:109-117.

Hales, L.S., Jr., and M.C. Belk. 1992. Validation of otolith annuli of bluegills in a southeastern thermal reservoir. Transactions of the American Fisheries Society 121:828-830.

Hill, T.D., and D.W. Willis. 1993. Largemouth bass biomass, density, and size structure in small South Dakota impoundments. South Dakota Academy of Science 72:31-39.

Hill, T.D., and D.W. Willis. 1994. Influence of water conductivity on AC and DC electrofishing catch rates for largemouth bass. North American Journal of Fisheries Management 14:202-207.

Hoxmeier, R.J.H., D.D. Aday, and D.H. Wahl. 2001. Factors influencing precision of age estimation from scales and otoliths of bluegills in Illinois reservoirs. North American Journal of Fisheries Management 21:374-380.

Jennings, M.J., J.E. Claussen, and D.P. Philipp. 1997. Effect of population size structure on reproductive investment of male bluegill. North American Journal of Fisheries Management 17:516-524.

Keast, A., and J. M. Eadie. 1985. Growth depensation in year-0 largemouth bass: the influence of diet. Transactions of the American Fisheries Society 114:204-213.

Koonce J.F., T.B. Bagenal, R.F. Carline, K.E.F. Hokanson, and M. Nagiec. 1977. Factors influencing year-class strength of percids: a summary and model of temperature effects. Journal of the Fisheries Research Board of Canada 34:1900-1909.

Krumholz, L.A. 1949. Rates of survival and growth of bluegill yolk fry stocked at different intensities in hatchery ponds. Transactions of the American Fisheries Society 76:190-203.

Latta, W.C., and J.W. Merna. 1977. Some factors influencing size of year class of bluegills (*Lepomis macrochirus*) in ponds. Michigan Academician 9:483-502.

Ludsin, S.A., and D.R. DeVries. 1997. First-year recruitment of largemouth bass: the interdependency of early life stages. Ecological Applications 7:1024-1038.

Maceina, M.J. 1997. Simple application of using residuals from catch-curve regressions to assess year-class strength in fish. Fisheries Research 32:115-121.

Miranda, L.E., and W.D. Hubbard. 1994. Length-dependent winter survival and lipid composition of age-0 largemouth bass in Bay Springs Reservoir, Mississippi. Transactions of the American Fisheries Society 123:80-87.

Miranda, L.E., and W.D. Hubbard. 1994. Winter survival of age-0 largemouth bass relative to size, predators, and shelter. North American Journal of Fisheries Management 14:790-796.

Mittelbach, G.G., and L. Persson. 1998. The ontogeny of piscivory and its ecological consequences. Canadian Journal of Fisheries and Aquatic Sciences 55:1454-1465.

Moore, W.G. 1942. Field studies on the oxygen requirements of certain freshwater fishes. Ecology 23:319-329.

Moran, P. A. P. 1953. The statistical analysis of the Canadian lynx cycle. II. Synchronization and meteorology. Australian Journal of Zoology 1:291-298.

Olson, M.H. 1996. Ontogenetic niche shifts in largemouth bass: variability and consequences for first year growth. Ecology 77:177-190.

Partridge, D.G., and D.R. DeVries. 1999. Regulation of growth and mortality in larval bluegills: implications for juvenile recruitment. Transactions of the American Fisheries Society 128:625–638.

Phelps, Q.E. 2006. Population dynamics of common carp in eastern South Dakota glacial lakes. M.S. thesis, South Dakota State University, Brookings.

Phillips, J. M., J. R. Jackson, and R. L. Noble. 1995. Hatch date influence on age-specific diet and growth of age-0 largemouth bass. Transactions of the American Fisheries Society 124:370-377.

Pope, K.L., D.W. Willis, and D.O. Lucchesi. 1996. Differential relations of age-0 black crappie and yellow perch to climatological variables in a natural lake. Journal of Freshwater Ecology 11:345-350.

Pope, K.L., D.W. Willis, and D.O. Lucchesi. 1997. Influence of temperature and precipitation on age-0 white bass abundance in two South Dakota natural lakes. Journal of Freshwater Ecology 12:599-605.

Ranta E, J. Lindstrom, and H. Lindén. 1995. Synchrony in population dynamics. Proceedings of the Royal Society of London: Biological Sciences 262:113–118

Santucci, V.J., Jr., and D.H. Wahl. 2003. The effects of growth, predation, and first-winter mortality on recruitment of bluegill cohorts. Transactions of the American Fisheries Society 132:346-360.

Schupp, D.H. 2002. What does Mt. Pinatubo have to do with walleyes? North American Journal of Fisheries Management 22:1014-1020.

Secor, D.H., J.M. Dean., and E.H. Laban. 1991. Manual for otolith removal and preparation for microstructural examination. University of South Carolina, Baruch Institute for Marine Biology and Coastal Research Technical Report 91-1, Columbia.

Stueven, E., and W. Stewart. 1996. 1995 South Dakota lakes assessment final report. South Dakota Department of Environment and Natural Resources, Pierre.

U.S. Department of Interior (USDI). 2001. 2001 National Survey of Hunting, Fishing, and Wildlife-associated Recreation. U.S. Government Printing Office, Washington, DC.

Werner, R.G. 1969. Ecology of limnetic bluegill (*Lepomis macrochirus*) fry in Crane Lake, Indiana. The American Midland Naturalist 81:164-181.

Werner, E.E., and D.J. Hall. 1979. Foraging efficiency and habitat switching in competing sunfishes. Ecology 60:256-264.